University of Technology, Sydney

A Study of Fluid Structure Interactions in Hydraulic Piping of Passive Interconnected Suspensions

by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signed

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Jing Zhao

Date:

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Jing Zhao
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TABLE OF CONTENTS

NOMENCLATURE & ACRONYM

Variables (for pipe wall or hose wall):

f_x	lateral shear force	F_x	lateral shear force amplitude
f_y	lateral shear force	F_y	lateral shear force amplitude
f_z	axial force	F_z	axial force amplitude
m_x	bending moment to x axis	M_x	bending moment amplitude to x axis
m_y	bending moment to y axis	M_y	bending moment amplitude to y axis
m_z	bending moment to z axis	M_z	bending moment amplitude to z axis
u_x	lateral displacement	U_x	lateral displacement amplitude
u_y	lateral displacement	U_y	lateral displacement amplitude
u_z	axial displacement	U_z	axial displacement amplitude
θ_x	rotate angle to x axis	Θ_x	rotate angle amplitude to x axis
θ_y	rotate angle to y axis	Θ_y	rotate angle amplitude to y axis
θ_z	rotate angle to z axis	Θ_z	rotate angle amplitude to z axis

Variables (for fluid):

p	axial pressure	P	axial pressure amplitude
v	axial velocity	V	axial displacement amplitude

Independent variables:

t	time	x	lateral axis
z	axial axis	y	lateral axis
x	lateral axis	ω	angular frequency

Coefficients:

A	cross-sectional area (m^2)
c_r	circumference of reinforcement of hose wall (m)
D	damping coefficient per unit length (s^{-1})
e	wall thickness (m)
E	Young's modulus of pipe wall (Pa)
E_x	lateral Young's modulus of hose wall (Pa)
E_z	axial Young's modulus of hose wall (Pa)
G	shear modulus of wall (Pa)

I	area moment of inertia (m^4)
I^M	moment of inertia (kg m^2)
J	polar moment of inertia (m^4)
K_E	modified bulk modulus of hose section (Pa)
K^*	modified fluid bulk modulus of pipe section (Pa)
l	length of section or distance (m)
L	inductance of hydraulic component
n	friction coefficient (s^{-1})
q	fluid flow (m^3)
r	inner radius of pipe/hose wall (m)
$\bar{r}$	mean radius of pipe wall (m)
r_r	radius of reinforcement of hose wall (m)
~~R~~	radius of curvature of pipe bend (m)
R	resistance of hydraulic component
~~V~~	volume of gas (m^3)
Z	impedance characteristics
γ	ratio of specific heats for nitrogen
η	rigidity factor for stiffness of elbow
κ	shear coefficient for hollow circle cross section
ν	Poisson's ratio of pipe wall
ν_x	lateral Poisson's ratio of hose wall
ν_z	axial Poisson's ratio of hose wall
ρ	mass density (kg/m^3)

Subscripts:

f	fluid
p	pipe wall
h	hose wall
m	concentrated mass
o	orifice
a	accumulator
ao	orifice at neck of accumulator
pre	manufacturer parameter of accumulator

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This thesis examines the fluid-induced high-frequency vibrations in the hydraulic pipelines of a recently invented vehicle suspension, namely Hydraulically Interconnected Suspension (HIS), which is applied to overcome the compromise between comfort and handling performance. The basic system of the suspension is a liquid-filled pipe-guided fluidic circuit, inside which the produced pressure changes often lead to vibrations of the whole pipeline and associated structures and hence become a source of noise. The results of this study can be extended to similar piping systems.

The modelling approach proposed here is necessarily multidisciplinary, covering vibration theory and fluid dynamics. The one-dimensional wave theory is employed to formulate the equations of motions that govern the dynamics of the fluid-structural system. Piping sections are defined as continuous line elements and discontinuities between the sections as point elements.

The Transfer Matrix Method (TMM) is applied to determine the relationships between individual components. The resulting sets of linear, frequency-dependent state-space equations, which govern the coupled dynamics of the system, are derived and then applied in a variety of ways. Key parameters that influence system dynamics are identified and analyses of their effects are presented.

The theoretical model is validated by experimental investigations. Two piping systems are assembled and free vibration results acquired through both the systems agree well with those of the proposed linear models. The deviation is reasonable and possible impact factors are described. However, the results from a different system configuration reveal the limitations in terms of the linear modelling to precisely represent curved hoses.

The methodology presented is found to be an effective and useful way of modelling liquid-filled pipe-guided piping systems, particularly in the frequency domain. The ob-

tained results suggest possible improvements can be made in relation to decreasing the fluid induced vibration in the piping system and the surrounding structures. However, further investigation is needed. For example, the development of the precise hose bend model or the coupling between the piping system and the connected structures could provide the topic of future studies.